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EMERGENCY IN-FLIGHT EGRESS OPENING FOR GENERAL AVIATION AIRCRAFT

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SUMMARY

In support of a stall/spin research program at the National Aeronautics and Space Administration (NASA), Langley Research Center (LaRC), an emergency in-flight egress system is being installed in a light general aviation airplane. The airplane has no provision for egress on the left side. A left-side egress opening would greatly enhance the pilot's ability for bailout, particularly in a right spin. To avoid a major structural redesign for a mechanical door, an add-on 11.2-kg (24.6-lb) pyrotechnic-actuated system was developed to create an opening in the existing structure. The skin of the airplane will be explosively severed around the side window, across a central stringer, and down to the floor, creating an opening of approximately 76 by 76 cm (30 by 30 in.). The severed panel will be jettisoned at an initial velocity of approximately 13.7 m/sec (45 ft/sec). System development included a total of 68 explosive severance tests on aluminum material using small samples, small and full-scale flat-panel aircraft structural mock-ups, and an actual aircraft fuselage. These tests proved explosive sizing/severance margins, explosive initiation, explosive product containment, and system dynamics. This technology is applicable to any aircraft of similar construction.

INTRODUCTION

Airplanes, upon stalling, may begin a rotating, sinking motion called a spin. Stall/spin is a prime causal factor in fatal general aviation accidents. Several light airplanes are being spin tested at NASA-LaRC in an effort to improve the stall/spin characteristics of this class of airplanes. These airplanes are equipped with tail-mounted spin recovery parachute systems in the event that the spinning cannot be stopped by the normal airplane controls. If both the airplane controls and the recovery parachute fail to stop the spin, the pilot would have to abandon the airplane. One airplane currently being readied for spin testing has a single door on the right side with no option for egress on the left side. Bailout would require the pilot to move across the aircraft to open the existing door, possibly against centrifugal loads; this is a difficult task at best. A left-side egress opening would minimize the pilot's bailout effort and time.

A pyrotechnic-actuated egress opening was developed because it proved to be more advantageous than a mechanical system on the basis of structural modification, performance, and the potential for success. A mechanical system would require considerable structural modification and reanalysis to incorporate a door and release mechanisms. A pyrotechnic approach would be an add-on system, based on previous experience gained in the F-111 and B-1 escape modules.

The pyrotechnic system developed in this effort uses a small-quantity, fully contained, explosive-shaped charge to sever and jettison a left-side panel from the airplane. The system is initiated mechanically by a bell crank pulled by the pilot. From that point, the system functions automatically. The design and development capitalized on existing pyrotechnic technology, materials, and components, and emphasized proving all aspects of functional performance. This proof of performance was accomplished analytically and functionally to show margins of capability greater than the force, strength, or energy required.

This paper describes the design, development, and functional testing of the pyrotechnic-actuated emergency in-flight egress opening for a NASA-LaRC general aviation research airplane.

APPARATUS

This section describes the off-the-shelf components that were qualified under previous aerospace programs and the test fixtures used in this program.

Flexible Linear-Shaped Charge (FLSC)

FLSC has been widely applied by the aerospace community in such applications as rocket vehicle staging and aircraft escape systems. Figure 1 shows a transverse cross section of FLSC. The materials used in this application are hexanitrostilbene II (organic-precipitated HNS II) explosive (3.19 g/m (15 grains/ft)) in a silver sheath. This explosive can only be initiated by a high explosive input (greater than 5.5×10^9 N/m² (800 000 psi)); it cannot be initiated by gunfire, lightning, electromagnetic-induced radiation, or physical handling. It will burn in a fire, but cannot achieve its cutting function. On initiation, the material detonates at a linear velocity of 7250 m/sec (23 800 ft/sec), generating 2.0×10^{10} N/m² (3×10^6 psi). The expanding gases and sheath materials are focused in the chevron to effect a metal penetration and deformation/breaking action.

FLSC Booster Tips

To assure reliable initiation of the FLSC and to seal the exposed explosive at the ends of the six lengths of FLSC, booster tips were installed. These tips are cups (4.83 mm (0.190 in.) i.d., 8.89 mm (0.35 in.) height) stamped from 0.15-mm (0.006-in.) 302 stainless steel (condition A) and loaded with hexanitrostilbene I (HNS I) at 2.20×10^8 N/m² (32 000 psi) to a height of 3.81 mm (0.150 in.). The cups were potted on the ends of the FLSC with a non-solvent structural adhesive (Scotch-Weld Brand Structural Adhesive 2216 B/A¹).

¹Product of 3M Company.

Lanyard-Actuated Detonator

The detonator used to initiate the FLSC is shown in figure 2. A 1.27-cm (0.5-in.) stroke compresses the linear spring to 89 N (20 lbf) resistance at release of the sear. The firing pin assembly is driven into the percussion primer to initiate the lead azide/HNS I explosive materials in the output cup. The lead azide provides an interface to develop the initiation flame to a detonation within a 2.54-mm (0.1-in.) column to properly initiate the HNS I, which in turn initiates an FLSC booster tip.

Manifolds

To properly locate, secure, and protect the FLSC booster tips, four 6061-T6 aluminum manifolds were attached to the skin and aircraft structures, one above and below the central stringer at the forward and aft extremities of the egress area. The aft manifolds contained a close-tolerance groove to secure the tips. However, the forward manifolds contained not only a groove but also a threaded port to receive the lanyard-actuated detonators at the correct relative position to the tips (minimum gaps of 0.50 mm (0.020 in.)) to assure reliable explosive initiation.

Internal Containment Development Fixture

To develop the internal structure required to contain the explosive blast of the FLSC, a test fixture was developed that would demonstrate performance margins. The fixture was an exact mock-up of a typical aircraft structure, but to demonstrate a containment margin, the explosive load was increased to 150 percent of the required amount and the mock-up of the aircraft skin thickness was increased to prevent any severance and venting of the explosive pressure. Further, the internal free volume within the containment structure, as well as the clearances of the FLSC to the structure, were reduced to the minimums expected in the aircraft.

Small-Panel Test Fixture

Wood-framed panels, measuring 45.7 by 45.7 cm (18 by 18 in.) were used as mock-ups of aircraft-representative structures for explosive severance tests. The mock-up skin was attached to the frame, and the representative full-scale structural elements, with explosive components, were mounted to the skin.

Full-scale, flat-panel test fixtures.— Two full-scale, light-airplane structures were mocked-up in wood-framed, flat-panels to evaluate the egress system performance. All materials (Alclad 2024-T4), material thicknesses (1.02 mm (0.04 in.)), and structural layouts, including a 3.175-mm (0.125-in.) thick plexiglass window, were mocked-up. A 3.8-cm (1.5-in.) square-mesh stainless wire (0.5 mm (0.020 in.) thick) was used on the second test to prevent the plexiglass from moving internally. A complete assembly, except for the initiation system, was tested.

Aircraft fuselage test fixture. - A center section of a typical airplane fuselage was modified to simulate the end application research-airplane structure as closely as possible, as shown in figure 3.

The research-airplane structure is fabricated from 1.02-mm (0.04-in.) Alclad 2024-T4 aluminum. The fuselage skin panels are made up of flat stock, overlapping above and below the window and just above the floor at the stringers. The depth of the formed channel frames, stringers, and ribs is 3.8 cm (1.5 in.). The frames are made up of flat stock mounted on the ribs in the central fuselage area. The 0.317-cm (0.125-in.) thick plexiglass window has an aperture of approximately 38.1 by 76.2 cm (15 by 30 in.). The major difference in the simulation was in the depth of frames, stringers, and ribs. The research-airplane depth is 3.81 cm (1.5 in.) and the test-fuselage depth was 6.35 cm (2.5 in.).

Final aircraft-designed containment, as well as the wire mesh of the window and initiation-system hardware, was used. The explosive severance was initiated by dropping a weight to actuate the control handle through a cable/pulley system.

A plexiglass witness panel was mounted inboard of the internal containment system at a distance of 21.6 cm (8.5 in.) from the mid-waterline (center stringer) of the egress opening. Dynamic pressure was monitored by two transducers mounted on the plexiglass panel in the proximity of the expected location of the pilot's head in the experimental airplane. One transducer was mounted 5.1 cm (2.0 in.) aft of the forward internal containment, and the other was 20.3 cm (8.0 in.) aft. High-speed cameras (400 and 4000 fps) filmed the system operation and dynamics from the front, side, and rear.

PROCEDURE

The description of the development of the egress system can be logically broken into six phases: system selection/development considerations; materials selection/system qualification; initiation-system development; explosive severance and containment development; full-scale, flat-panel tests; and aircraft fuselage mock-up test.

System Selection/Development Considerations

A mechanical or pyrotechnic system could provide the required egress opening. The selection and development of this emergency in-flight egress system were based on the following:

1. Minimizing structural impact to the aircraft
2. Minimizing pilot effort and response time to actuate
3. Minimizing system weight
4. Maximizing egress opening area

5. Minimizing pilot egress interference
6. Providing jettisoning force of egress panel
7. Providing passive, low-maintenance system
8. Providing maximum system reliability

Materials Selection/System Qualification

The pyrotechnic materials and techniques used in this egress system were selected on the basis of previous aerospace design experience and previously qualified components and systems.

Initiation-System Development

The initiation subsystem was designed and developed with safety considerations paramount. The selection and development of the initiation system were based on the following characteristics:

1. Independent system, isolated from onboard systems
2. Manageable actuation force
3. Fully secure in flight
4. Additional safetying measures on the ground
5. Positive "stops" to assure that the actuation is complete
6. Accessibility and reliability

The complete initiation subsystem actuator (no detonators) was mounted on a flat-plate breadboard to evaluate the actuation forces required to overcome internal static and kinetic friction. The 89-N (20-lbf) maximum resistive force of the lanyard-actuated detonator was applied to the cable, and the pull forces necessary to overcome friction were measured.

Explosive Severance and Containment Development

The development of the explosive severance technology progressed through several phases:

1. Size the flexible linear-shaped charge and determine severance performance margins under worst-case conditions (a double thickness of aluminum and increasing the thickness beyond the expected limits). Also, determine the cutting performance of the FLSC and booster-cup combination inside the manifolds. Past experience indicated that any foreign material such as potting in the

chevron area of the FLSC destroys the cutting efficiency. Tests were conducted on double-thickness plates (1.016 on 1.016 mm (0.040 on 0.040 in.)).

2. Develop an external containment system to contain the explosive products outside the fuselage and provide a jettisoning force to the severed panel. A demonstration of the development was made by using small-panel test fixtures.

3. Develop a method of severing the central stringer in the egress area. Again, small-panel test fixtures were used to demonstrate the local-area performance.

4. Develop a method of containing the explosive products inside the fuselage, assuring a performance margin. By using the internal containment development fixture described in the Apparatus section, containment tests were conducted under worst-case conditions of:

a. 150 percent of the required explosive load was used, 3.19 g/m (15 grains/ft) RDX (cyclotrimethylenetrinitramine) instead of 2.13 g/m (10 grains/ft)

b. No explosive pressure venting

c. Minimum volumes

d. Filling the volume with closed-cell, flexible foam (used to preclude contamination of the containment volume)

e. Proximity of the FLSC to the aircraft and containment structure

Full-Scale, Flat-Panel Tests

To develop an understanding of system-level performance, tests were conducted on the full-scale, flat-panel test mock-ups described in the Apparatus section. Performance parameters to be evaluated were complete severance, neatness/uniformity of severed edges, effect on aircraft structure during severance, capability of the containment structure (particularly at the stringer) to stop explosive products internally, jettison velocities and dynamics of the severed panel, and capability of the window mesh to prevent internal entry of the plexiglass window fragments on panel jettison.

Aircraft Fuselage Mock-up Test

To demonstrate the final system design, a full-scale aircraft fuselage mock-up test was conducted. This test included actuating the mechanical initiation subsystem with both detonators installed, the final design of the containment system (particularly at the stringers) with closed-cell foam to prevent volume contamination, and the 3.8-cm (1.5-in.) protective wire mesh on the inside of the window to prevent the plexiglass from moving internally. Internal explosive debris and pressure were monitored with a plexiglass panel across the entire egress area.

RESULTS

System Selection/Development Considerations

Two candidate egress systems could meet the considerations outlined in the Procedure Section - mechanical and pyrotechnic.

The mechanical system approach would require a large structural modification and design effort to incorporate a door frame and door. This would be followed by a release system, such as pulling hinge pins and actuating the latches, which could require considerable pilot effort and time. The released door may then require (according to flight conditions) manual and aerodynamic jettison. Finally, a considerable effort may be required to validate the structural design of the modified aircraft under the high-stress, spin-pullout conditions.

The pyrotechnic system approach would use a flexible linear-shaped charge (FLSC) to sever the existing skin and structure, following proven principles, applications, and materials. A minimal aircraft modification could be expected, that is, attaching the explosive and containment to the existing structure. A pyrotechnic system would require little effort to initiate and, as a completely independent energy source, would produce a highly responsive severance and jettisoning capability. Since the expected structural changes would be minimal, no new load paths or structural analysis would be expected or necessary. Based on these considerations, the pyrotechnic system was selected for development.

Materials Selection/System Qualification

The flexible linear-shaped charge (FLSC) has been applied to several aerospace systems, including the F-111 (ref. 1) and the B-1 aircraft, in which the cockpit is severed from the fuselage. The FLSC materials, organic-precipitated hexanitrostilbene (HNS II) in a silver sheath, were developed specifically for thermal and age stability (ref. 2); applications include the F-14, F-16, and AH-1G (Cobra) aircraft. The booster tip materials, HNS I in a steel cup, are applied almost universally to aircraft explosive transfer systems. The lanyard-actuated detonator was qualified for the F-14, F-15, and the Space Shuttle Orbiter. The capability of the FLSC to withstand severe environments is demonstrated by its many applications. The functional qualification was based on component and system development, emphasizing performance margins described in subsequent sections.

Initiation-System Development

The initiation system developed in this effort is shown in figure 4. A 40° rotational stroke of the handle assembly (9.9 cm (3.9 in.)) produces 4.95 cm (1.95 in.) pulley rotation and cable withdrawals. The cables thread through guide tubes to provide 90° redirected pulls on the lanyards of the detonators. Since a 1.27-cm (0.5-in.) stroke is required to actuate the detonator, a margin of at least 3 to 1 exists. Each cable is fitted with a

clevis fork to adapt to the detonator and a ball which is captured by a plate on the pulley. The cable lengths were adjusted to prevent simultaneous engagement/actuation of the detonators, which would result in twice the load.

Safety features were incorporated in the system to prevent inadvertent system actuation on the ground and in flight. The handle and pulley assembly is secured to the mounting plate by a ball-release bayonet safety pin for ground safety. An aluminum shear pin, again securing the handle and pulley assembly to the mounting plate, prevents inadvertent actuation without the safety pin for flight. Furthermore, the left-side cover posts (fig. 4) act as motion stops; the upper-post stop prevents forward motion of the handle, and the lower post provides a stop to assure that full actuation has occurred. A cover plate protects the entire pulley assembly and cable/tube ends. The entire assembly is mounted on the forward frame beside the pilot, just aft of the instrument console. The handle is positioned just above the lower extremity and 2.54 cm (1.0 in.) aft of the instrument panel.

The initiation-system breadboard revealed that the 3.175-mm (0.125-in.) diameter, pure-aluminum shear pin sheared at 137.9 N (31 lbf). Furthermore, the static friction of either cable (preloaded to 89 N (20 lbf)) required only 93 N (21 lbf) at the handle. Actual friction loads will be much less in the system, since an 89-N (20-lbf) load will occur only at maximum stroke of the detonator, which occurs dynamically.

Explosive Severance and Containment Development

The 68 explosive tests are briefly outlined in table I to establish the explosive severance and containment approaches and performance margins. The results of the explosive sizing and performance comparisons are shown in table II. In determining the ability to sever double-skin thicknesses, the FLSC, composed of 2.125 g/m (10 grains/ft) RDX (cyclotrimethylenetrinitramine), could sever/break the 1.016- on 1.60-mm (0.040- on 0.063-in.) aluminum, which provides a performance margin of 58 percent. Furthermore, a 131-percent margin is achieved by using an HNS II FLSC of 3.188 g/m (15 grains/ft) instead of the 2.125 g/m RDX, resulting in an overall performance margin approaching 100 percent.

In evaluating the performance of the booster tip/FLSC combination under manifolds, it was determined that the increased quantity of explosive (due to the tips) easily ruptured a single skin thickness and, with minimal potting, could rupture two skin thicknesses. An already initiated tear would progress through the relatively short lengths where FLSC penetration did not occur.

The effectiveness of the external containment approach in the small-panel tests is shown in figures 5 and 6. The no-containment test (fig. 5) produced ragged edges (large deflections) on both the severed panel and the aircraft skin mock-up. The containment test (fig. 6) produced smooth, neat edges on both the panel and the aircraft skin. Although the containment-test panel weighed nearly three times as much, no loss in jettison velocity occurred compared with the no-containment test. The external containment is a 1.60-mm

(0.063-in.) thick cold-rolled steel coverplate (3.81 cm (1.50 in.) wide, as required), separated from the skin by a 3.15-mm (0.125-in.) aluminum-plate standoff. The bent-down portion closes the cavity and smooths the surface, reducing aerodynamic drag. The cavity between the steel and the skin was necessary to assure adequate deflection of a double-thickness skin to allow reliable severance/fracture. A 1.60-mm (0.063-in.) cavity allowed only partial severance. The final design of the external containment is shown in figure 7 on the aircraft fuselage mock-up of the egress system.

To reliably sever the central stringer, two lengths of explosive were used. One length was laid along the skin, through a hole in the stringer (inside the bend radius of the channel), and across the leg of the channel; the other length was laid around the stringer and matched into common booster tips at each end. This arrangement introduced two problems: determining the reliability of severing the double-thickness material (stringer and skin) with the larger standoff to avoid the stringer radius, and determining how to manage the structural damage and deformation caused by the doubled quantity of explosive. Several tests with larger standoffs than required indicated sufficient energy existed to sever and tear the material with an adequate margin. The doubled quantity of explosive required doubling the structural attachment bolts (2.54-cm (1.0-in.) centers) and using steel internal containment structure on the severed panel.

The internal containment structure to protect the pilot from explosive products is shown in figure 8. The cross-sectional lines indicate the locations of subsequent structural views.

The principles of the internal explosive containment are shown in figure 9 (section A-A). The skin is severed by the explosive, causing the structure to the right to be jettisoned downward with the panel. The explosive products are contained within the free volume formed by the stringer, the angle to the right, and the cover channel. A cover channel is used to prevent a left rotation of the cover plate and stringer due to the explosive pressure. The two cover plates above the channel stiffen the channel and cover the gaps at the cover-channel interfaces. The reinforcement angle prevents shearing damage from the close proximity of the explosive. The closed-cell foam (95-percent air) prevents contamination of the free volume. If this volume were filled with water (no foam), considerable deformation of the containment structure could occur, possibly causing pilot injury.

The same approach as described above is shown in figure 10 (section B-B), except a cover angle attached to the aircraft ribs is used to prevent rotation rather than a channel. The cover angle is curved to match the aircraft contour. The severed/jettisoned portion of the structure is below the stringer.

Figure 11 (section C-C) and figure 8 show the complicated welded stainless-steel containment structure used at the forward and aft sections of the central stringer. The structure attaches to the frames above and below the stringer. In order to maintain an internal free volume to dissipate the explosive energy of the flexible linear-shaped charge around the stringer, the structure had to project inboard into the cockpit. Also, this structure had to accommodate the post-assembly installation of the detonators and initiation-cable guide tubes.

An approach similar to section H-B is shown in figure 12 (section D-D), except that the cover angle is attached to the frame. Furthermore, there is no need for a reinforcement angle; the explosive was not mounted against the frame.

Full-Scale, Flat-Panel Tests—

The full-scale, flat-panel tests confirmed a number of system principles as well as detecting system problem areas. The explosively severed edges of the skin and jettisoned panel were smooth and uniform. The dynamics of the severed panels were uniform and predictable. The panel was smoothly released and pitched horizontally; the base of the panel swung upward in the direction of motion. However, the external containment structure and skin detached from the panel in the areas beneath the doubled FLSC around the central stringer, allowing explosive gaseous products to enter the fuselage.

The gases, created on detonation of the explosive, sharply load the entire area within the internal explosive containment, causing the skin to deflect between the bolt attachments to exhaust the gases. These gases are highly visible as flame and smoke. The flame is a secondary burning of the unreacted carbon on mixing with the air. The flame duration in both tests was approximately 21 msec, an unlikely ignition source of even the most reactive materials.

The manifold attachments and the plexiglass window retention were inadequate on the first test and were corrected on the second test. The manifolds (attached only through the skin) pulled loose; attachments through the frame prevented detachment. The window broke up due to panel/frame oilcanning, tossing several pieces inboard. A 3.8- by 3.8-cm (1.5- by 1.5-in.) wire mesh was stretched across the window and attached to the internal containment structure to eliminate internal debris.

The jettison capabilities demonstrated in the flat-panel tests (small and full scale) are summarized in table III. Although the system weight increased, the amount of energy delivered per unit weight was consistent.

Aircraft Mock-up Test

Figures 13 and 14 show the neat, predictable, severed edges of the skin and the frame around the opening created by the internal containment. No internal debris was detected by the witness panel or high-speed camera coverage (4000 pps). The internal pressures measured were 34.5 kN/m^2 (5 psi) and 17.7 kN/m^2 (2.5 psi) with a duration of less than 1.0 msec. These pressure levels compare favorably with measurements made on the British aircraft Jet Provost Mk.5, which employs an explosive cord-actuated overhead-canopy severance system. Measurements at the chest level of dummies indicated pressures of 50.3 to 117 kN/m^2 (7.3 to 17 psi). However, pressure levels at the dummy ears (inside the helmet) were approximately 26.2 kN/m^2 (3.8 psi).

The flame duration and jettison velocity were considerably improved by the room temperature-vulcanizing (RTV) compound application on the external containment. The actual duration of the flame was less than 5 msec. The

improvement of the containment prevented carbon particle and air mixing and burning. Furthermore, the jettison velocity (table III) increased 28 percent due to the improved sealing of the explosive-gas pressure wave. The severed panel weighed 6.62 kg (14.6 lb) and achieved a velocity of 13.7 m/sec (45 ft/sec).

The severed panel was completely intact, except for the window, following the test (figs. 15 and 16). The wire mesh prevented any window fragments from entering the fuselage. The frame created by the external containment was smooth and uniform, and the skin was securely attached in all areas.

CONCLUSIONS

A pyrotechnic-actuated, in-flight egress opening has been developed and qualified for use in a light, general aviation research airplane. This system will allow the pilot to bail out from the left side of the airplane.

The egress system is simple and highly responsive, requiring minimal airplane modifications to incorporate. A complete, full-scale aircraft fuselage mock-up demonstrated the ability of the system to create an opening of approximately 76 by 76 cm (30 by 30 in.), including the window, in the cabin side. The total system weight was 11.17 kg (24.6 lb). The opening was created by small-quantity explosives (flexible linear-shaped charge) which severed and jettisoned a 6.62-kg (14.6-lb) portion of the fuselage skin and structure at a velocity of 13.7 m/sec (45 ft/sec). The explosive products are contained, presenting no debris or sound/pressure hazard to the pilot. Furthermore, the opening created is neat and smooth, presenting a minimal interference potential to the pilot on egress.

System reliability has been demonstrated by previous aerospace system applications and by functional tests. The pyrotechnic components and performance principles have been qualified on aircraft systems such as the F-111 and B-1 escape modules. All functional parameters have been tested for this application to demonstrate substantial performance margins (a greater capability than required to accomplish the desired function). The system will require no maintenance, except for a 5-year replacement cycle on the detonator.

This egress system technology is applicable to any aircraft of similar construction.

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1. Schimmel, M. L.: The F-111 Crew Module: Major Challenge for Thermally Stable Explosives. McDonnell paper presented at the Symposium on Thermally Stable Explosives at the Naval Ordnance Laboratory (White Oak, Maryland), June 23-25, 1970. (Available as MDC 70-019.)
2. Bement, Laurence J.: Application of Temperature-Resistant Explosives to NASA Missions. NASA paper presented at the Symposium on Thermally Stable Explosives at the Naval Ordnance Laboratory (White Oak, Maryland), June 23-25, 1970.

TABLE I.- EXPLOSIVE DEVELOPMENT TESTS

Explosive sizing/severance tests	23
Manifold development	5
Containment	29
Small-scale mock-ups	8
Full-scale mock-ups:	
Flat	2
Aircraft	1
Total test specimens	68

TABLE II.- EXPLOSIVE SEVERANCE TESTS AND COMPARISON

(a) Explosive severance tests

Explosive, g/m (grains/ft)	Material severed, mm. (in.)		
	1.016 on 1.016 (0.040 on 0.040)	1.016 on 1.60 (0.040 on 0.061)	1.60 on 1.60 (0.063 on 0.063)
1.488 (7) RDX	Yes	No	
2.125 (10) RDX	Yes	Yes	No

(b) Explosive severance comparison (2024-T4 tapered plates)

2.125 g/m (10 grains/ft) RDX will cut 1.53 mm (0.0602 in.) } 131-percent
 3.188 g/m (15 grains/ft) HNS II will cut 2.00 mm (0.0788 in.) } increase

TABLE III.- PANEL JETTISON COMPARISONS

Type test	Weight of severed panel, kg (lb)	Velocity of severed panel, m/sec (ft/sec)	Energy per unit weight of severed panel J/kg (ft-lbf/lb)
Small-scale (no containment)	0.34 (0.76)	9.8 (32)	48.2 (15.9)
Small-scale (with containment)	1.00 (2.2)	10.4 (34)	53.2 (17.9)
First mock-up (flat panel)	3.40 (7.5)	10.7 (35)	58.8 (19.0)
Second mock-up (flat panel)	5.94 (13.1)	10.7 (35)	57.2 (18.9)
Fuselage mock-up	6.62 (14.6)	13.7 (45)	94.0 (31.4)

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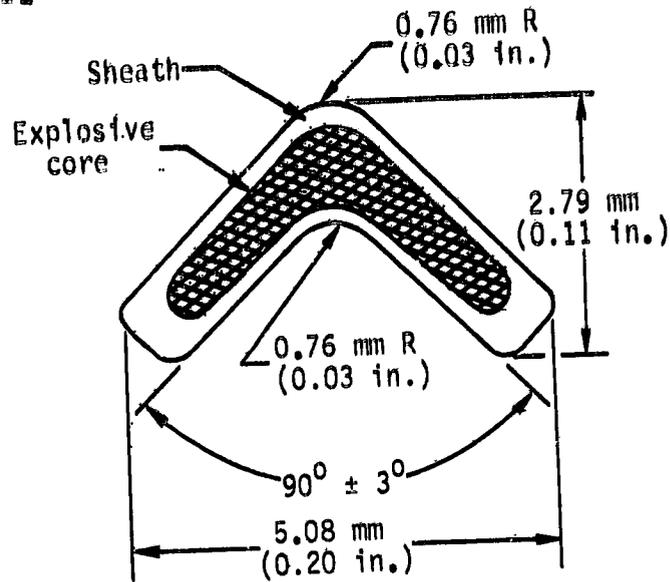


Figure 1.- Cross section of silver-sheathed HNS II flexible linear-shaped charge.

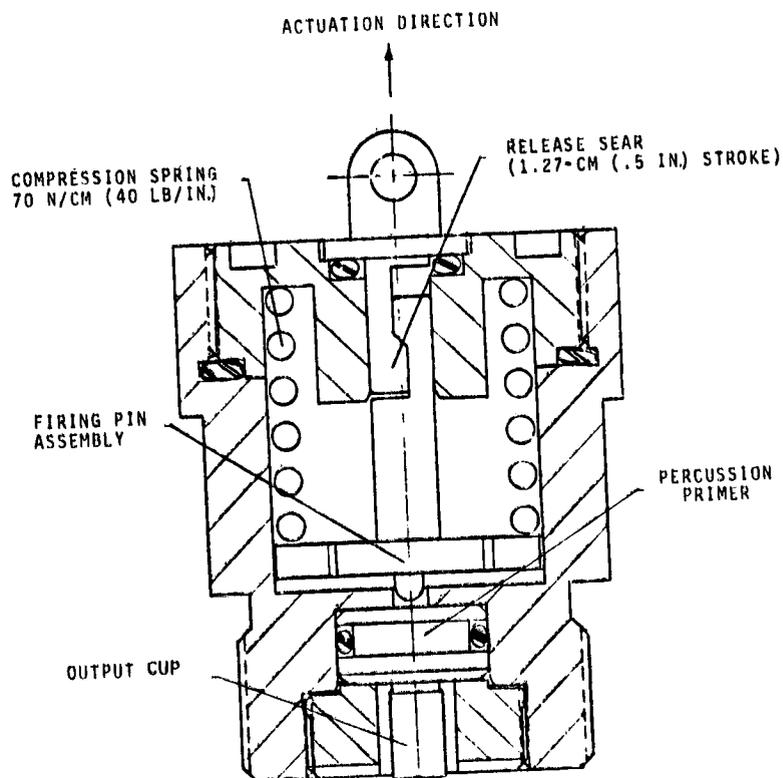
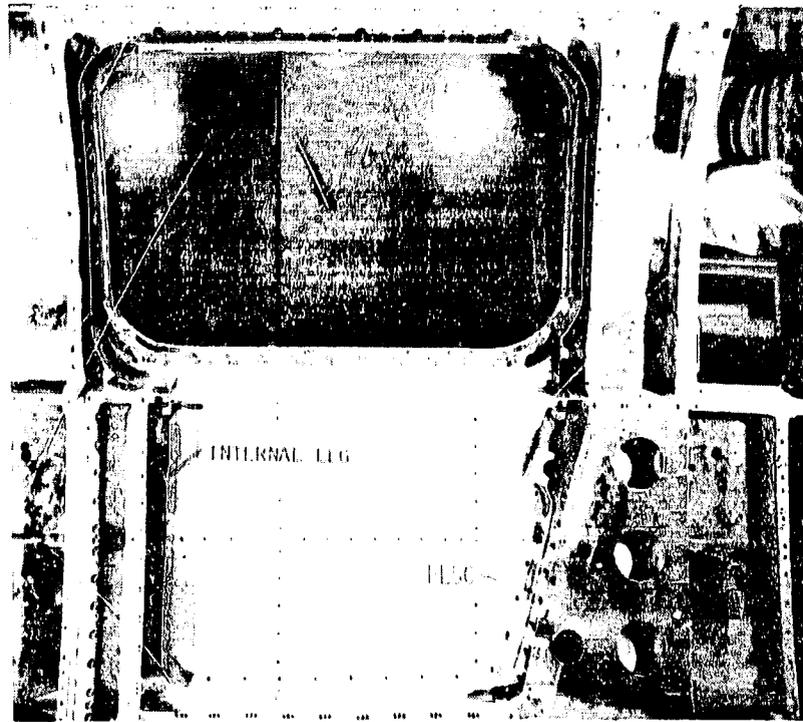
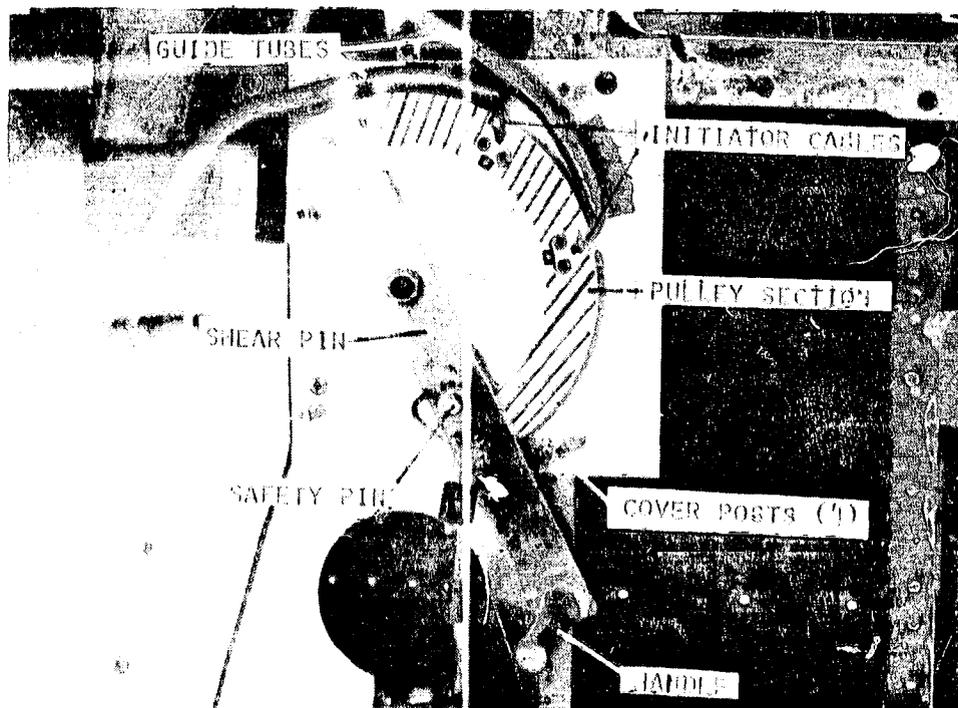


Figure 2.- Cross section of lanyard-actuated detonator.



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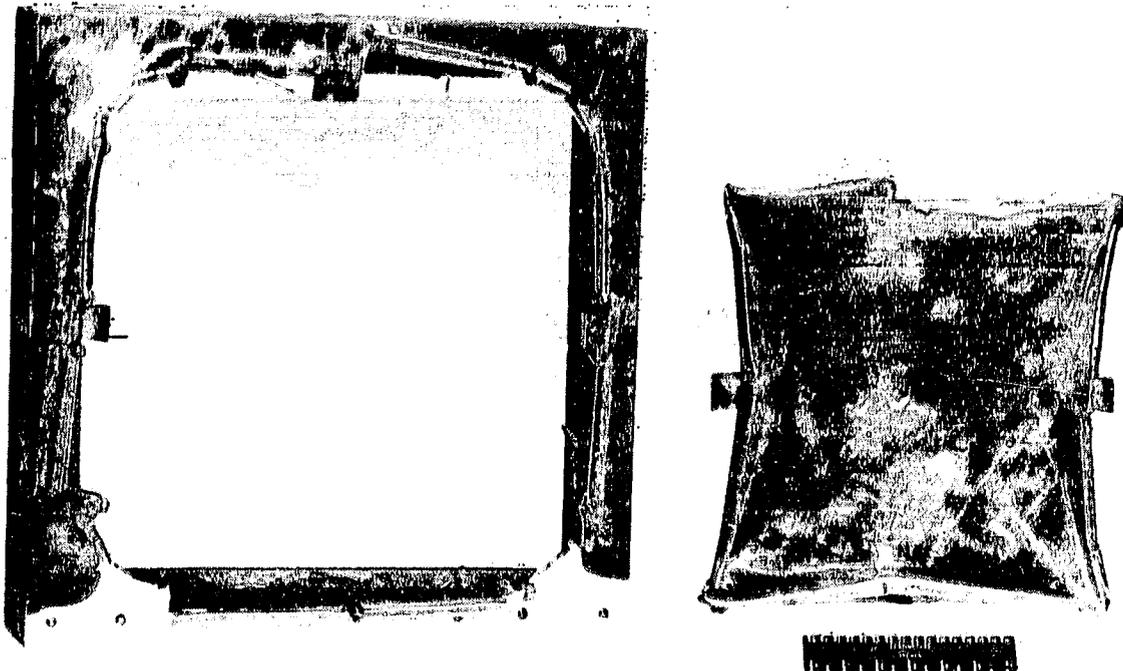
Figure 3.- Internal view of aircraft fuselage mock-up.



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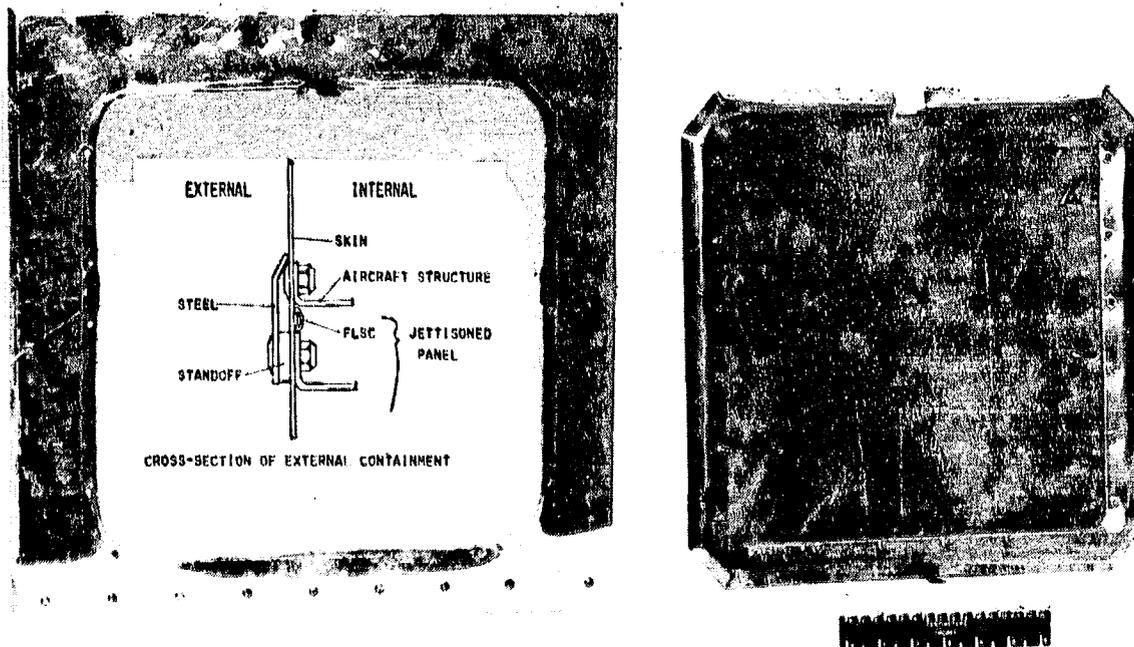
Figure 4.- Mechanical initiation system.

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Figure 5.- Small-panel severance test with no external containment.



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Figure 6.- Small-panel severance test with external containment.

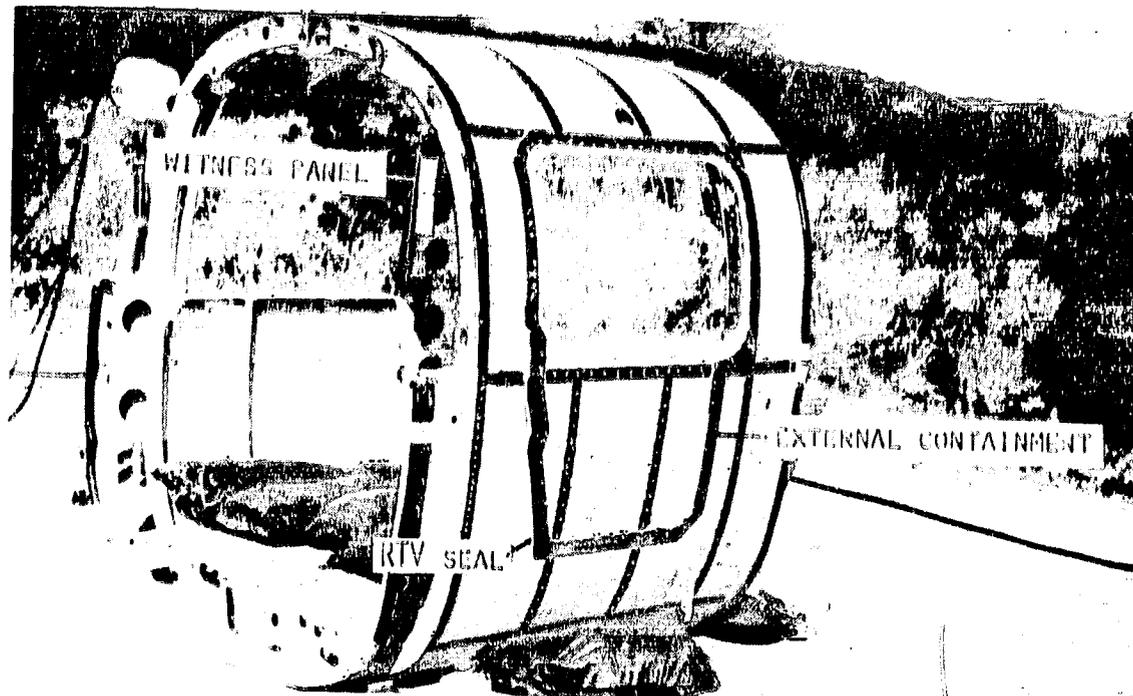


Figure 7.- External view of fuselage mock-up of egress system. L-80-117

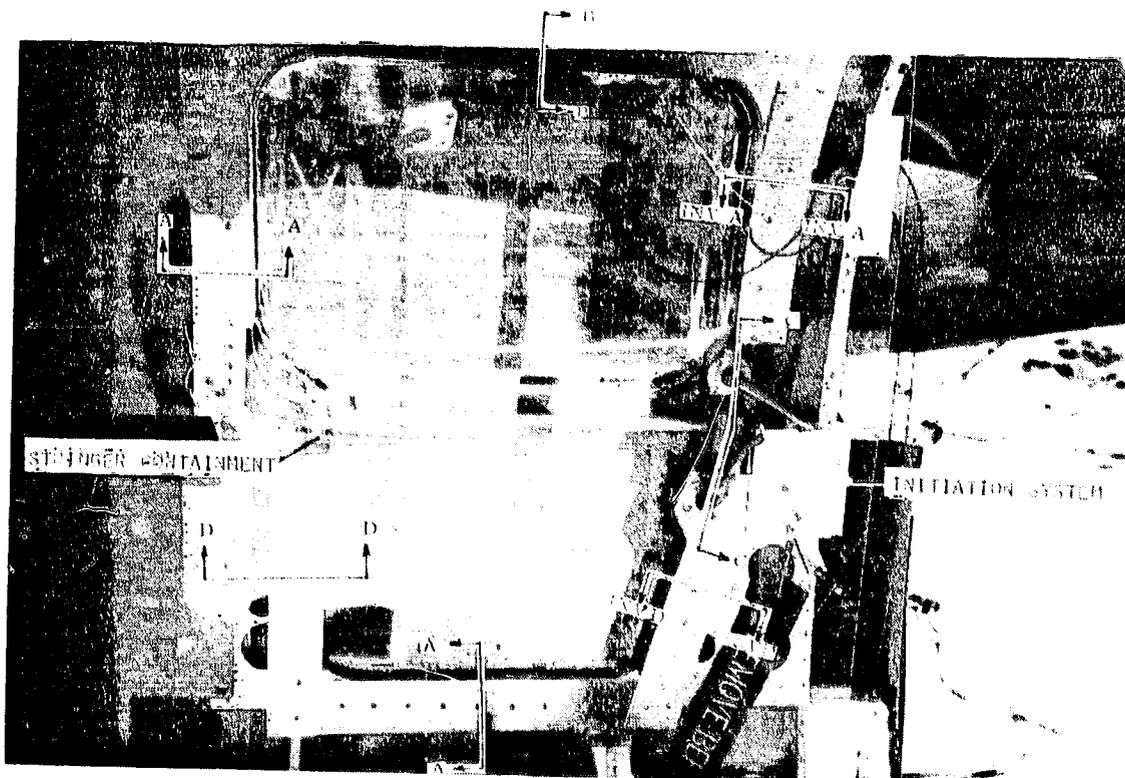


Figure 8.- Internal view of fuselage mock-up of egress system. L-80-118
 (Section views indicate subsequent illustrations.)

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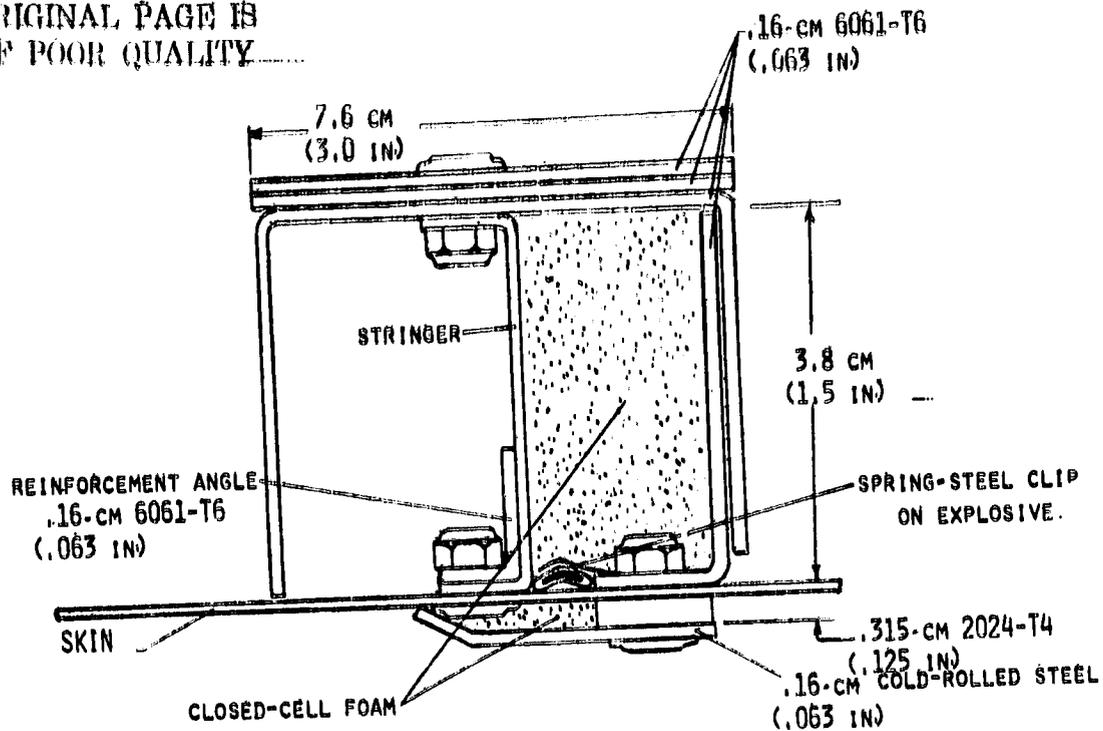


Figure 9.- A-A and inverted A-A cross section of internal containment.

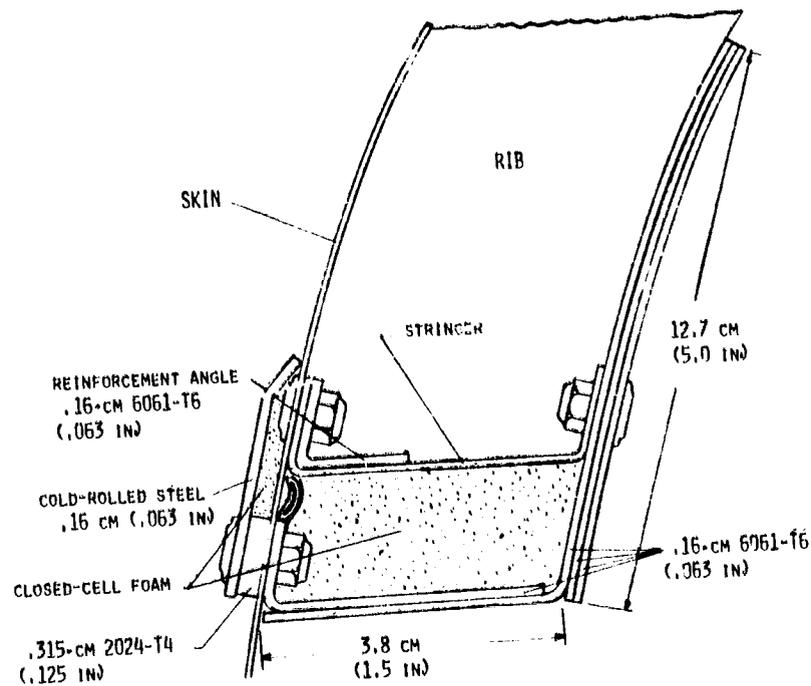


Figure 10.- B-B cross section of internal containment.

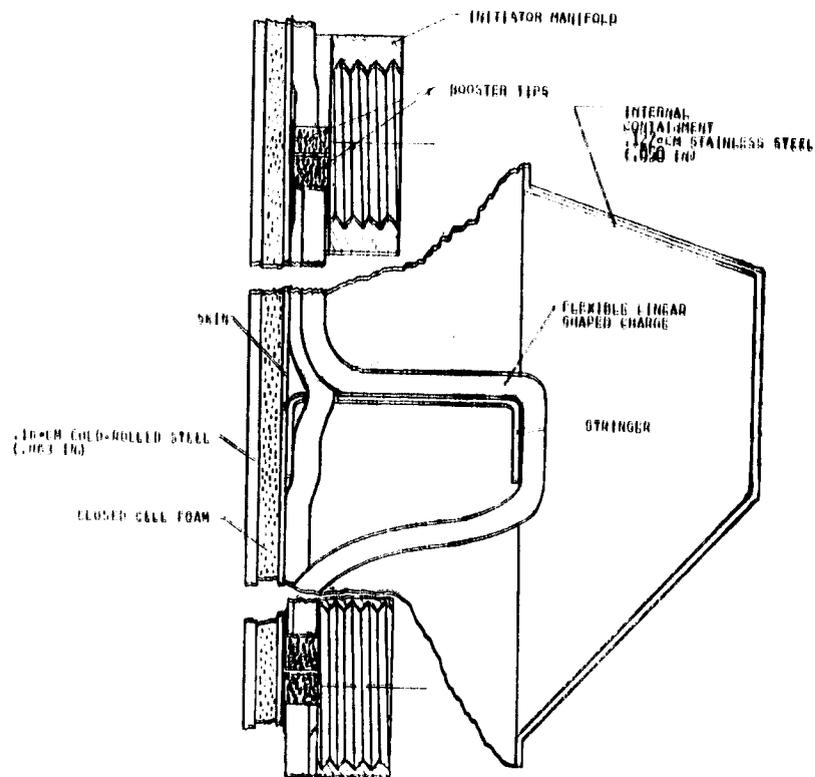


Figure 11.- C-C cross section of internal containment.

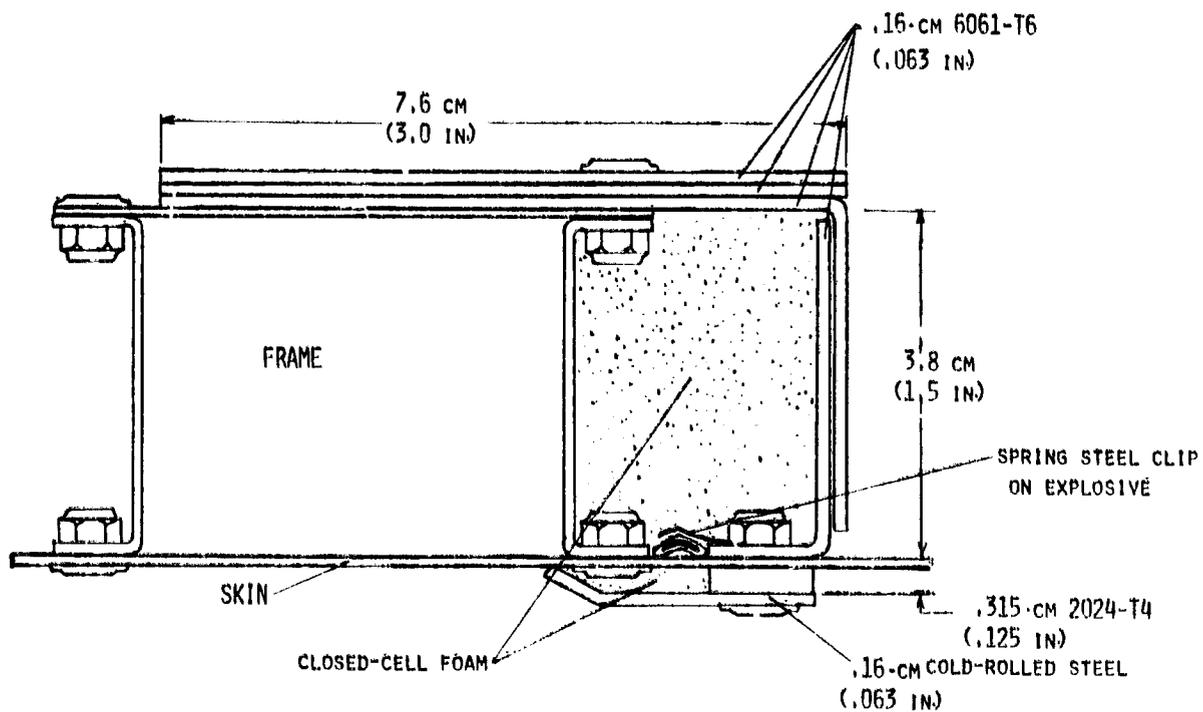
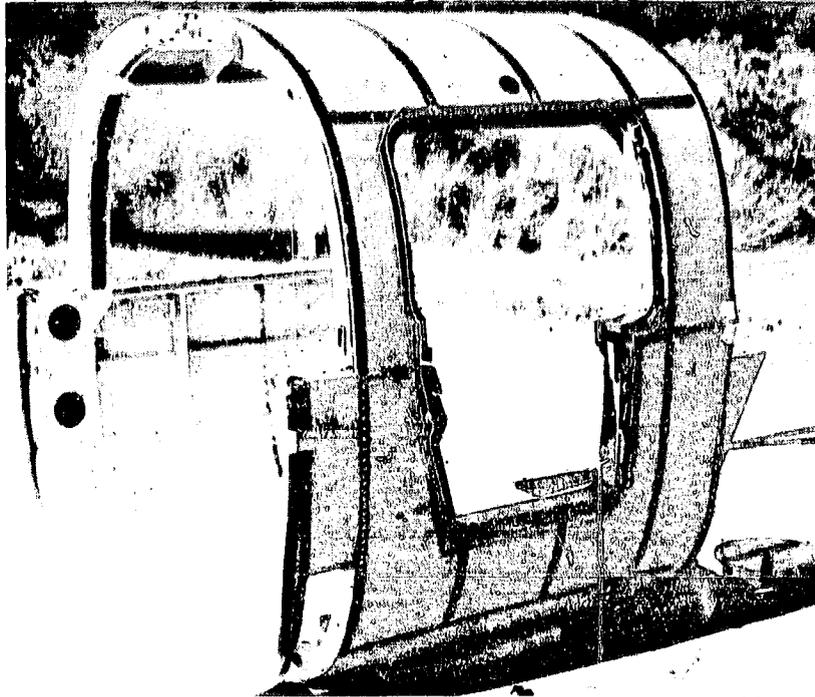


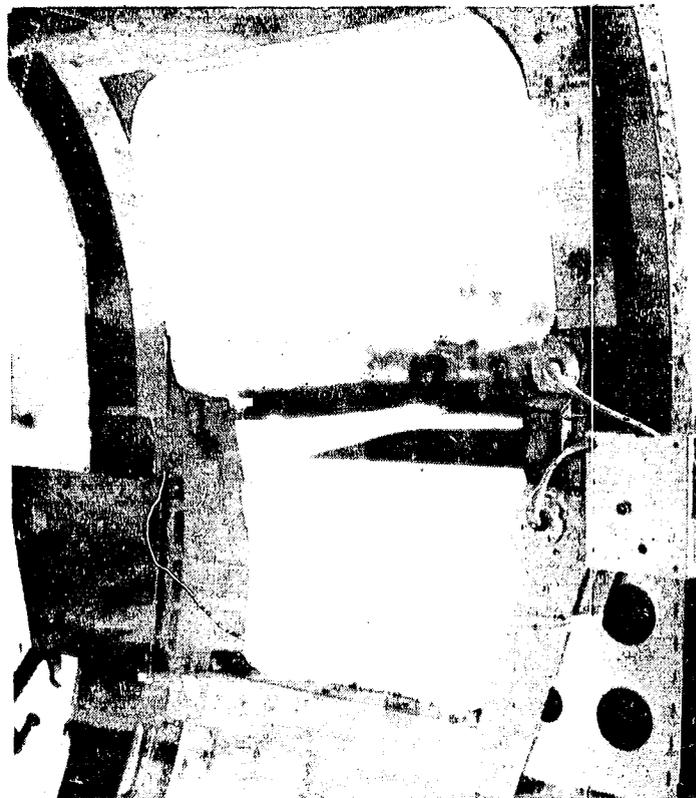
Figure 12.- D-D and inverted D-D cross section of internal containment.

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Figure 13.- Post-test external view of fuselage mock-up of egress system.



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Figure 14.- Post-test internal view of fuselage mock-up of egress system.

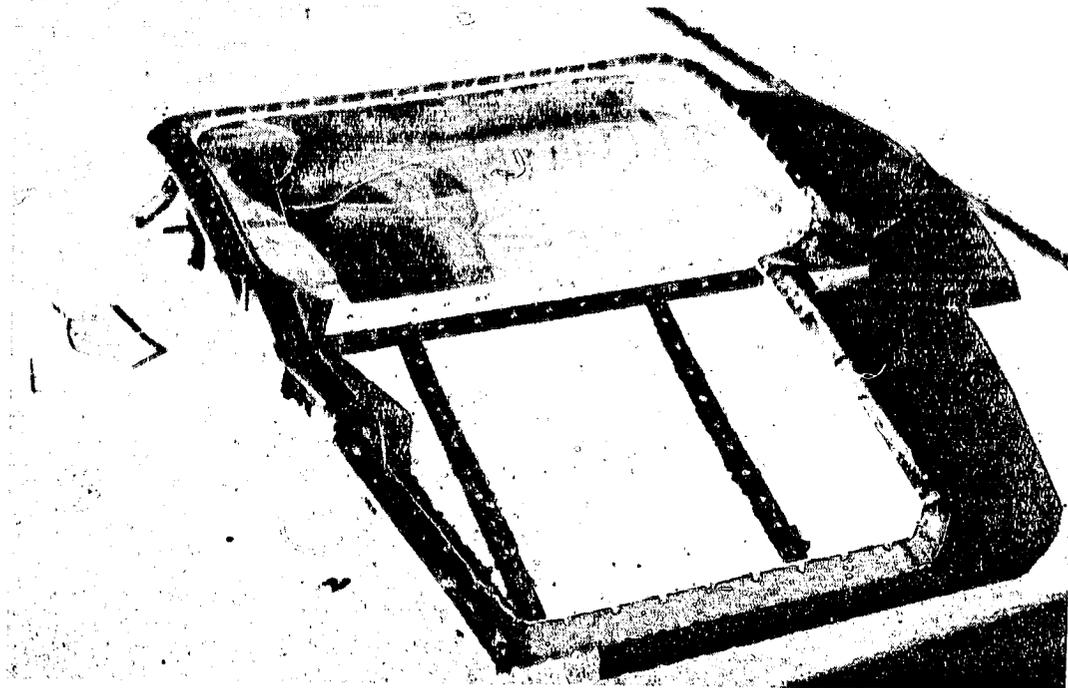


Figure 15.- External view of severed panel.

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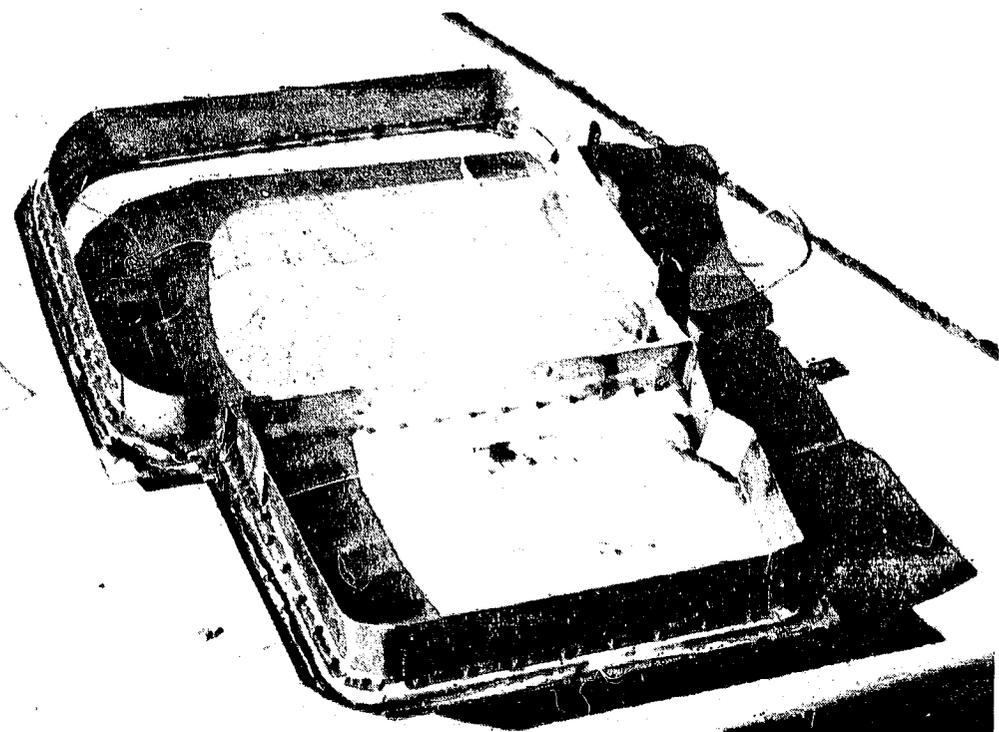


Figure 16.- Internal view of severed panel.

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